

# **Assessment of Additional Corrective Measures**

**Logan Landfill  
Gallatin County, Montana**

**August 2006**

Prepared by:



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## **Introduction**

The Logan landfill in Gallatin County, Montana is located about four miles east of Three Forks and about two miles southeast of Logan, Montana (Figure 1). The facility has been in use since at least the early 1970s and operated with unlined waste cells until the mid-1990s. Volatile organic compounds (VOCs) were detected at the facility at the inception of groundwater monitoring in 1990. Very low levels of solvents, refrigerants and propellants have been detected in most of the wells at the facility since that time. Levels of tetrachloroethene (PCE) increased to a point in 1998 at which the Human Health Standard of 5.0 micrograms per liter (ug/l) was exceeded in one well at the northern facility boundary. Concentrations of PCE have remained constant or increased since that time.

A Corrective Measures Assessment (CMA) was completed for the facility in 2000. The preferred alternative involved removing municipal solid waste from an unlined area proximal to the wells most impacted by the VOC contamination. Upon completion of the bulk of this alternative, a two-year period of no action was allowed by the Montana Department of Environmental Quality (DEQ) to determine if the remedial action was effective. Subsequent groundwater monitoring data indicated that the VOC concentrations in groundwater were not impacted by the removal of the waste, so in accordance with the Administrative Rules of Montana (ARM) 17.50.710 (8) (b), the facility operators are required to revise the potential treatment options and present them to the DEQ.

## **Purpose and Scope**

The purpose of this document is to briefly review the previously-generated data, present additional site-specific data, and review potential remedial options. This report will present only the basic information presented in the previously-submitted CMA. Much of the investigative work conducted for that study is not pertinent to the existing situation, since much of it involved the location and delineation of historical waste fill areas. A significant amount of work has been conducted for this investigation on subsurface conditions, including the installation of additional monitoring wells, and the sampling and analysis of soil and groundwater for VOCs. Some information, such as logs of previously-installed monitoring wells, is not included herein. The review of potentially feasible remedial options is intended as a screening effort, not as a remedial technique to be applied on the basis of information collected for this document. Additional site-specific data will need to be acquired in order to refine the actual implementation of a specific remedial application.



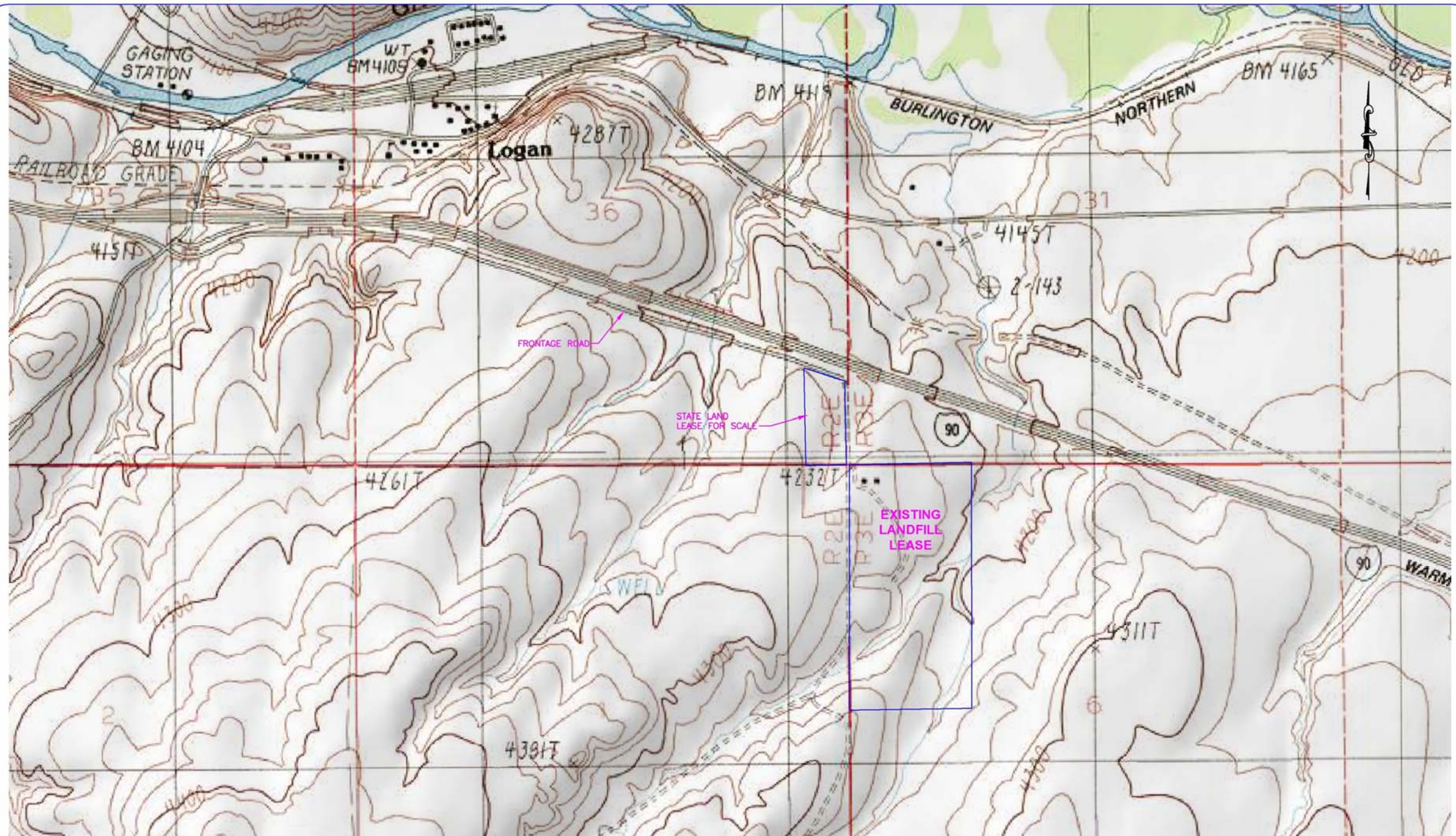


Figure 1. Location map of the Logan Landfill, Gallatin County, Montana.





## Background

The specific history of the facility is discussed in detail in the previously-submitted CMA. Very briefly, the landfill has been in operation since at least the early 1970s and operated with unlined waste cells until the mid-1990's.

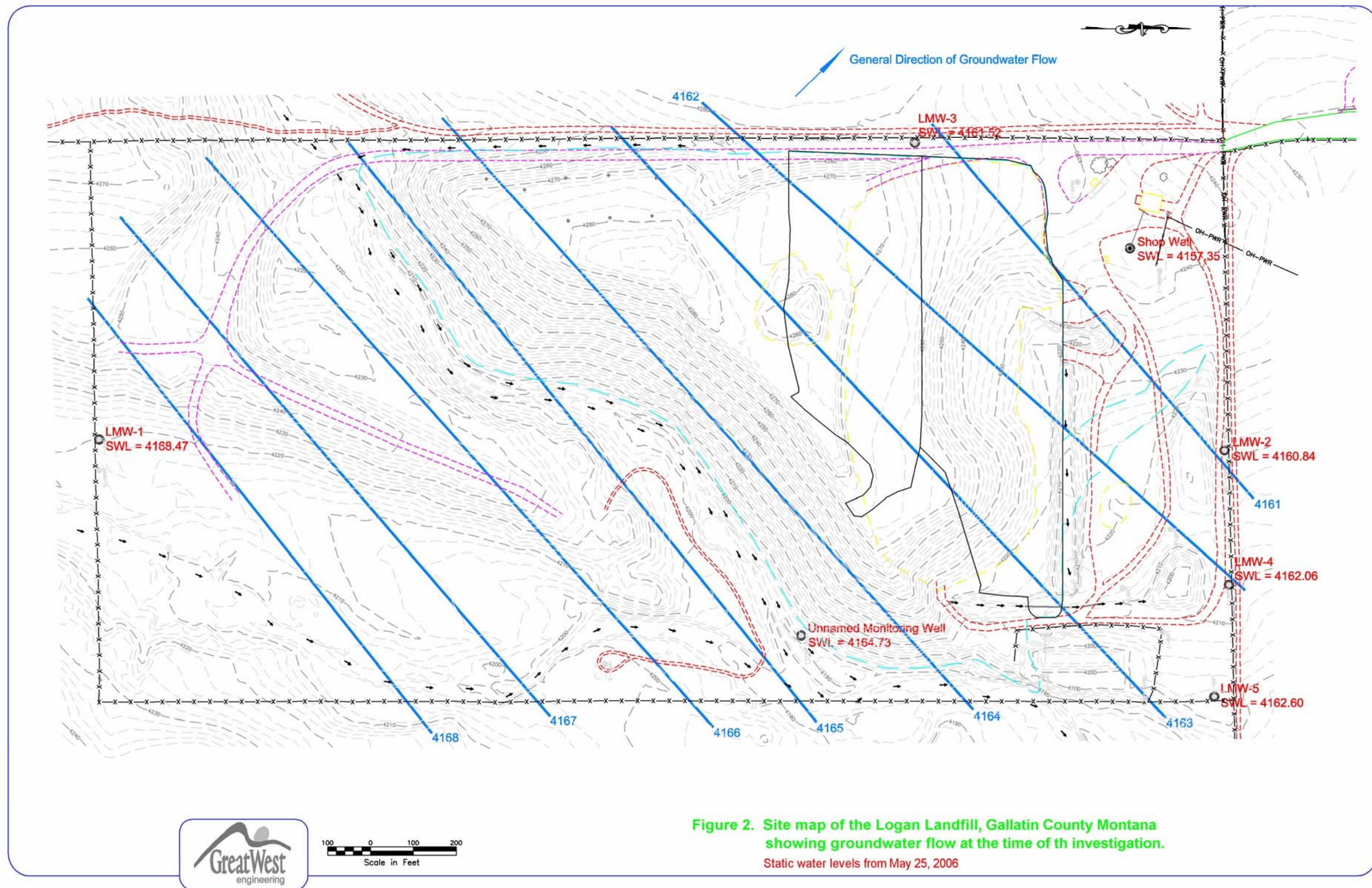
Three wells were installed initially, one on the southern boundary, in the center of the northern boundary and one on the western boundary close to the edge of the historical waste pile (Figure 2). The southernmost well serves as the background well, against which the chemistry of the other wells is compared. If levels of certain chemicals or ions in the down-gradient wells are higher than the background, then there is a possibility that contamination may be leaking from the landfill via leachate or other mechanism.

Initially, some volatile organic compounds were detected in samples taken from the two down-gradient wells. However, other aspects of the groundwater chemistry indicated that there was no evidence of leachate leaking into the uppermost aquifer. Nonetheless, the presence of the VOCs prompted the installation of two additional wells along the northern facility boundary. By mid-1994 the DEQ had placed the facility into Assessment Monitoring.

The Assessment Monitoring phase did not initially demonstrate the presence of significant contamination or any human health hazard. Samples taken in 1999, however, showed a significant increase in certain contaminants. The greatest concern was for a human health exceedance for tetrachloroethene, the source of which is probably dry-cleaning solution. The Human Health Standard established by the State of Montana sets the maximum contamination limit (MCL) at 5 micrograms per liter (ug/L) for PCE. The levels of PCE in monitoring well LMW-4 commonly exceed 8 ug/L.

A CMA was submitted to the DEQ in April, 2000. That CMA determined that the delineation of the PCE/VOC plume would be very difficult, and that the plume had not been clearly defined at that point in time. Also, the original CMA pointed out the difficulty of locating a specific source for the PCE. Given those limitations, the original preferred alternative consisted of removing a portion of the existing historic waste in hopes of discovering the source of the PCE. The old waste was removed over the course of several years and in 2003 the facility was allowed to adopt a "No Action" alternative for a two-year period in order to determine the effectiveness of the waste removal as a control mechanism for the source of the PCE.

As of 2005, the groundwater analytical data indicated that the PCE plume was still present and showed no signs of dissipating. The DEQ requested a new CMA because none of the original options were viable and new technologies



have been developed in the past five to ten years that have been shown effective for the removal of VOCs in groundwater.

## **2006 Subsurface Investigation**

The Gallatin County Solid Waste Management District, in response to the regulatory requirements noted above, initiated an effort to satisfy several questions that needed to be answered in order to accomplish a satisfactory understanding the nature of the contamination and the contaminant migration pathways. The first question involved the source of the PCE and the second question involved the chemical's migration into and through the uppermost aquifer. This required additional knowledge of the subsurface environment, which is best obtained through drilling test borings, logging the drill cuttings, and submitting soil and water samples for chemical analysis. This phase of the project was initiated in May, 2006. The results of the work are discussed below.

### **Test Borings**

The test borings were drilled with conventional air rotary methods. While this is not necessarily the optimal method in all cases, the depth of the water table and the known presence of resistant strata precluded the use of a hollow-stem auger. The locations of the test borings, denoted as wells LMW-6 through -9, are noted on Figure 2. Logs of the borings are included in Appendix A. The four borings were completed by the drilling contractor as monitoring wells with two-inch Schedule 40 PVC flush-threaded riser and screen. Depths of the holes varied, generally as a result of the subsurface conditions. The aquifer host at the facility consists of medium to coarse sand with minor gravel. The formation is very loose, and completion of deep wells was inhibited by collapse of the holes soon after retraction of the bit and drill stem. Thus, some holes are deeper than the point at which the wells were completed.

The geological materials encountered in each well are shown on the well logs in Appendix A. The reader will note that the correlations between the various units found in the test borings are tenuous, at best. That is, a readily identifiable unit found in one test boring does not appear at the same elevation in other wells. In many cases, such units are simply not found from one location to another. Figure 3 shows an example of the stratigraphic complexities as found in a surface excavation that lies just to the west of test boring LMW-8. The material seen on the left side of the outcrop consists of a poorly-sorted fine- to medium-grained sand that appears to be a section cut across a fluvial (stream-laid) deposit. The darker material on the right comprises sandy silt and clay. Note that the contact between the two is very convoluted and essentially vertical in its configuration. Thus, two test borings set five feet apart at the surface above this location would yield very different well logs. The strike or dip of these strata are



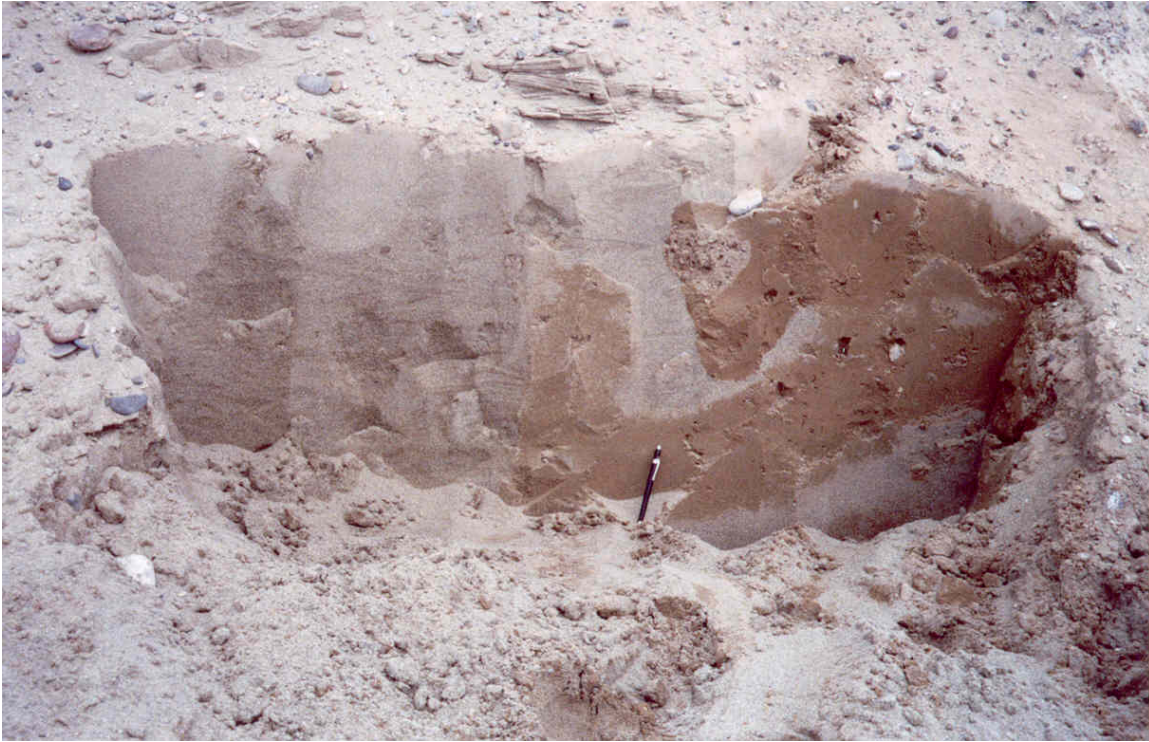


Figure 3. Photograph of typical stratigraphic contact between silty sand (light grey, left and center of photo) and stiff clay (reddish brown, right of photo) in a cut at the Logan landfill, Gallatin County, Montana.



difficult to obtain, and the value of such data in this particular sedimentary environment is questionable.

The one consistent element found in all of the test boring locations is that the water-bearing sands were found at relatively similar elevations, and most locations hosted silty and/or clayey deposits just above the saturated sand.

### **Chemical Analyses**

**Soils.** The investigators collected samples of the soil either from drill cuttings or from split-spoon samples and submitted them to an analytical laboratory for analysis for VOCs as found on Table 1 in ARM 17.05.708 (Appendix B). None of the soil samples were found to contain VOCs.

**Groundwater.** Upon completion of the wells, the investigators developed, purged and sampled the wells via disposable bailers. The samples were submitted to an analytical laboratory for VOC, pH and specific conductance analysis. The analytical reports for these samples are included in Appendix B. VOCs were detected at some level in all of the samples. A discussion of the concentrations of the various VOCs and what that means in terms of the contaminant plume follows.

## **Results and Discussion**

The objective of the subsurface study, as noted above, was to further refine the nature of the geology at the site and to delineate the PCE plume. The information obtained from the subsurface investigation has provided significant satisfaction toward that end, although some “holes” in the characterization remain, and additional questions have arisen.

### **Geology and Groundwater**

As previously noted, stratigraphic correlations at this facility are nearly impossible to attain. The nature of the alluvial/fluvial depositional environment makes for very problematic interpretations of down-hole data. In general, however, it is clear that this is a sand- and silt-dominated system. While some strata consist of gravel and coarse sand, the bulk of the materials above the water table consist of fine sand, silt and clay. Very few of the strata are very well lithified, and most of those consist of reddish or greenish siltstone. In spite of the generally fine-grained nature of most of the strata, the poor level of lithification will facilitate relatively easy penetration by fluids. Anecdotally speaking, there is not often standing water found at the facility, and the landfill staff note that the facility dries out relatively quickly after rain events.

Thus, the geology of the facility appears to accommodate relatively high levels of infiltration. The depositional environment would result in a tortuous path for downward-migrating fluids, but this migration would not be seriously inhibited by any naturally occurring facility-wide sub-surface barrier, such as a single thick clay bed. That is to say there was no single geological structure found above the water table that would facilitate the northeastward migration of fluids from the waste fill area to the area of known groundwater contamination.

The static water levels in all wells at the facility were obtained by the investigators and the direction of groundwater flow thereby established at the time of the field investigation. A map showing the water table elevation is shown in Figure 2. The four new monitoring wells appear to yield significant quantities of water, although the investigators did not attempt to conduct aquifer tests to quantify those values. Given that the aquifer intercepted by the new wells appears to be quite similar to that described in previously-completed monitoring wells, it is likely that the new wells can produce well over 10 gallons per minute (gpm).

### **Contaminant Plume**

The contaminant plume consists of two major categories of VOCs: the dry-cleaning solution consisting of tetrachloroethene, 1,1,1-trichloroethane (TCA) and their respective degradation products composing one group, and low levels of propellants and refrigerants composing the other group. The compounds of concern for this study are the PCE and TCA, which are solvents. TCA is a degreaser that is commonly included in with the PCE in dry-cleaning solutions. The propellants and refrigerants occur commonly in the vadose zone and groundwater at many landfills as a result of formerly common disposal practices related to discarded household refrigerators and freezers.

The recently-obtained data refine the nature of the plume and lead the investigators to develop a number of conclusions that will allow for the implementation of an appropriate remedial application. In order to facilitate that discussion, however, some preliminary elements regarding the nature of PCE and its subsurface behavior must first be examined.

**Contaminant Migration.** PCE and TCA are included in a group of chemicals known as “dense non-aqueous phase liquids,” or DNAPLs. These chemicals are denser than water and, in their liquid form, do not dissolve particularly well in water. These properties result in migration pathways that are very different from their lighter counterparts, such as petroleum products. Petroleum, because it is less dense than water, essentially “floats” to the top of the aquifer, creating relatively straightforward plumes that can, in most instances, be readily defined. The lighter contaminants almost act only in two dimensions; that is, while some constituents will move downward into an aquifer through mixing or slight density differences, the bulk of the contaminants remain in the upper part of the aquifer.

Conversely, DNAPLs tend to move vertically through groundwater relatively quickly, and disperse throughout the aquifer quite readily. Further, because DNAPLs are not very soluble in water, they are able to collect in zones or pockets within the aquifer. This is known as “pooling.”

The density of DNAPLs and their physical qualities also inhibit their spread relative to the capillary conditions in the aquifer. That is, water will move more freely through the spaces between the soil grains than the DNAPL. Consequently, contaminants can remain pooled or concentrated in small quantities throughout large areas of an aquifer for extended periods, up to many decades.

**Contaminant Degradation.** Tetrachloroethene consists of a hydrocarbon molecule with four chlorine ions attached to it. The natural degradation process, which under natural conditions is facilitated by anaerobic bacteria, involves the stripping of the chlorine ions. Removal of one chlorine ion results in trichloroethene. Removal of two ions results in one or more of the dichloroethene family (such as dichloroethene, cis-1,2-dichloroethene). With one chlorine ion, vinyl chloride is formed. Finally, the molecule is stripped down to ethylene.

1,1,1-trichloroethane, with the loss of a chlorine ion, degrades to dichloroethane. It is important to note that under certain chemical conditions, PCE can also degrade to one or another species of dichloroethane. Further losses of chlorine ions from dichloroethane results in vinyl chloride and, finally, ethylene.

**Plume Characteristics.** The contaminant plume at the Logan landfill has now been better defined, but some elements of the situation remain to be resolved. Figures 4, 5, 6 and 7 show the concentrations of tetrachloroethene, trichloroethene, 1,1,1-trichloroethane, and dichloroethane, respectively. Before interpreting these graphics, the reader must bear in mind two critical facts. First, the wells are not placed on a dense, evenly spaced geometric grid and, as such, the data will be skewed due to gaps in the sampling network. Second, the screens of the wells are not all traversing the same thicknesses of the aquifer. That is, some of the well screens encompass the entire thickness of the saturated zone while others only partially penetrate it.

Given the nature of DNAPL subsurface migration, it would be nearly impossible to delineate all of the potential locations of pooling. Wells would have to be installed on a very close spacings, perhaps on the order of ten to fifteen feet apart. In addition, the installation of wells would doubtless remobilize and smear the contaminants, further complicating the characterization of the aquifer. Thus, some further characterization of the plume may be warranted, but DNAPLs are notoriously difficult to “chase,” and future investigators need to take care in the planning and execution of any further refinements in plume delineation.



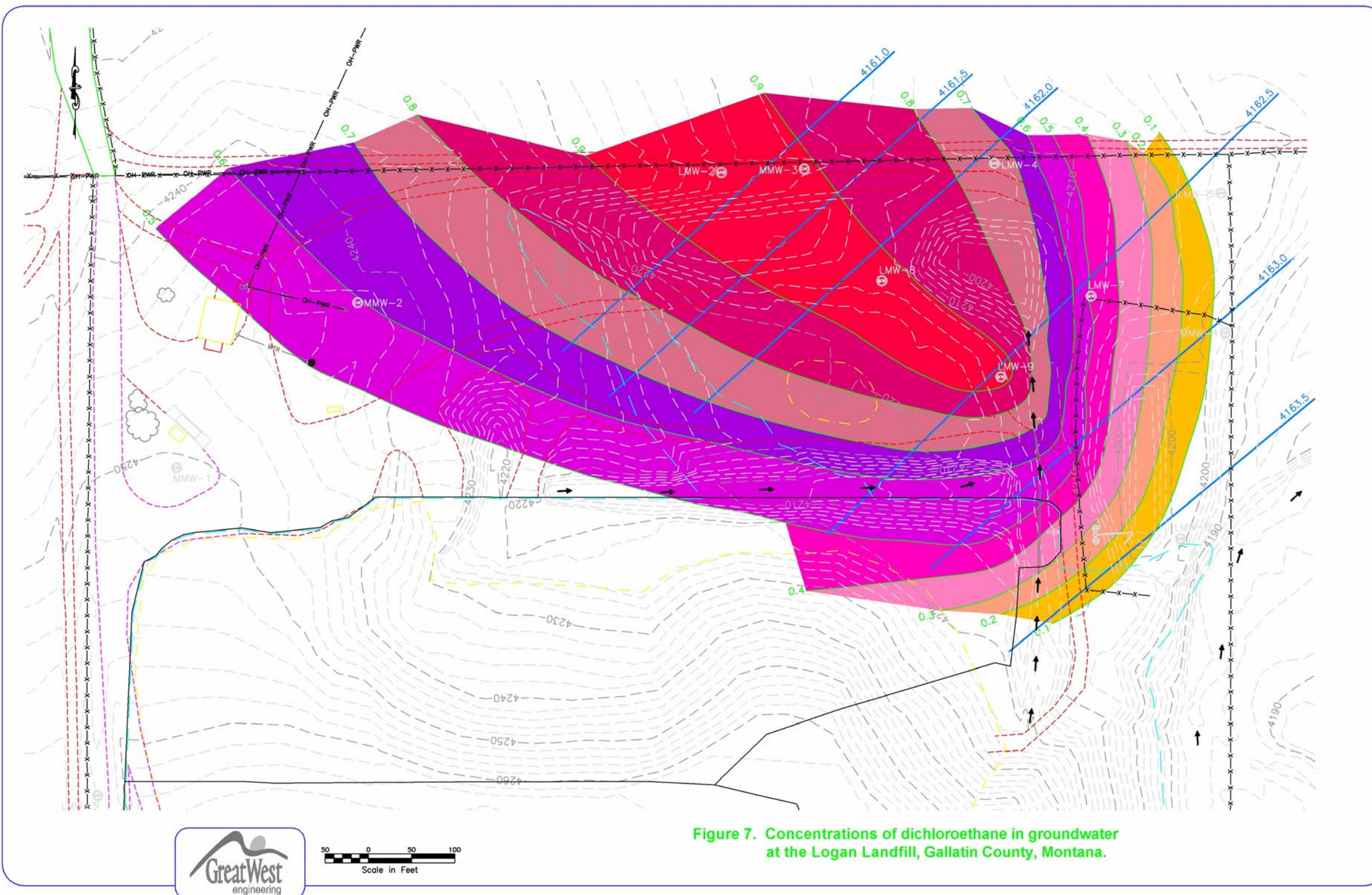


Figure 7. Concentrations of dichloroethane in groundwater at the Logan Landfill, Gallatin County, Montana.



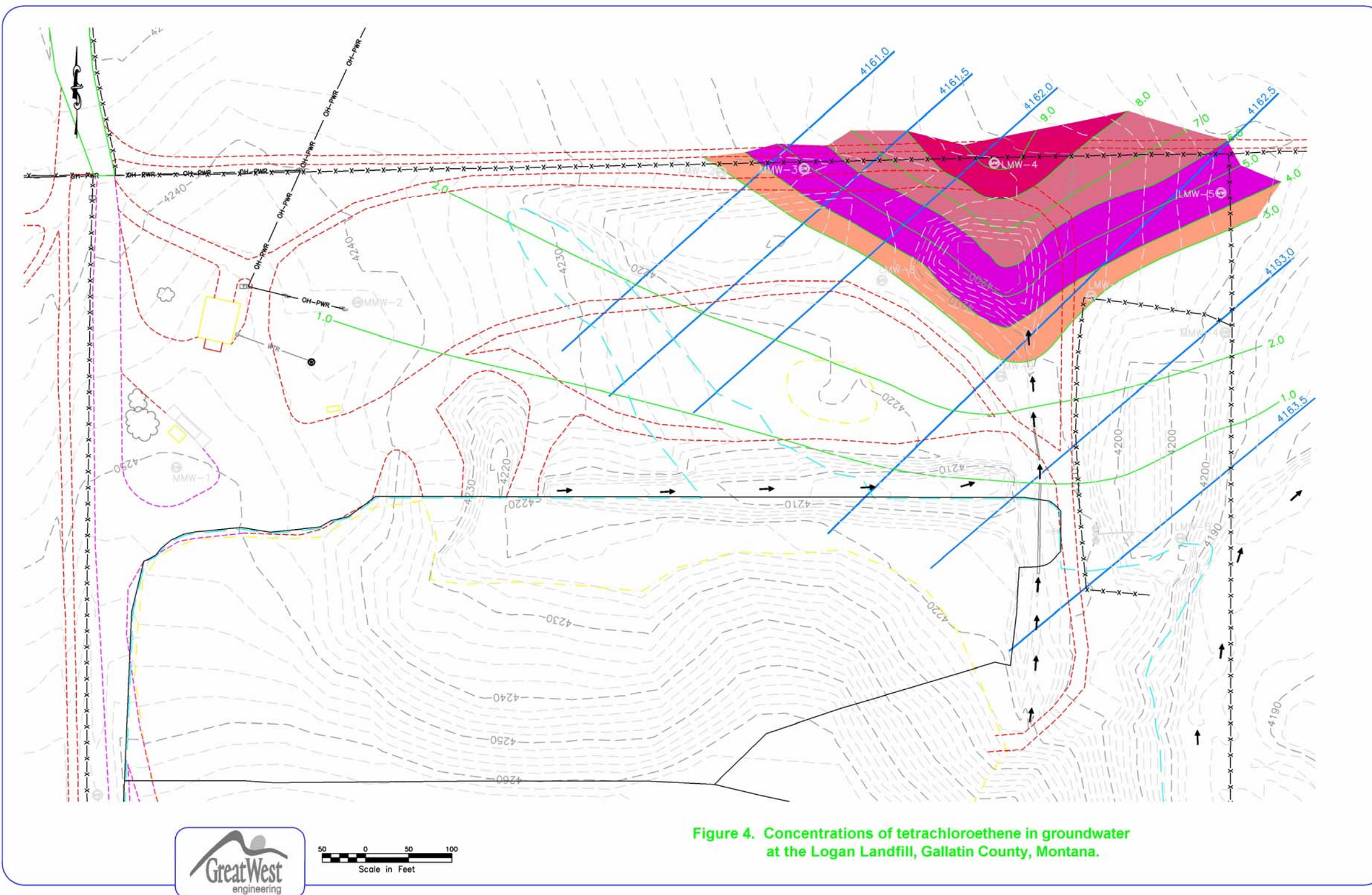
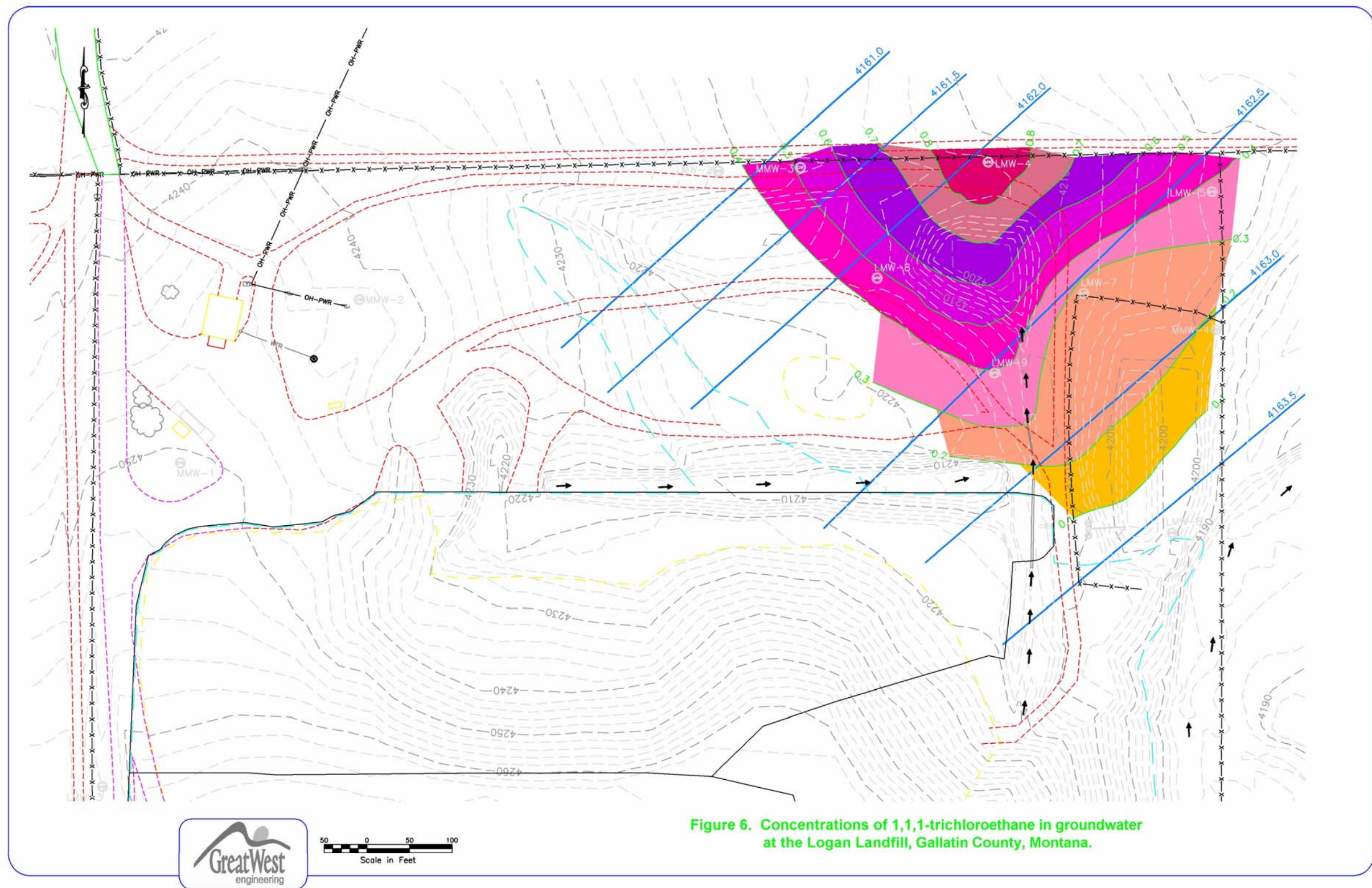


Figure 4. Concentrations of tetrachloroethene in groundwater at the Logan Landfill, Gallatin County, Montana.









Given those caveats, it appears that the highest concentrations of the first three of those four DNAPLs (Figures 4 through 7) are found near LMW-4. This gives the appearance that the source of the DNAPL is near that point, with contaminant concentrations decreasing in a southerly direction. This is not possible, given the nature of DNAPL behavior in groundwater and the direction of the aquifer flow: The groundwater flows to the northwest, not the north. It is much more likely that there are sources near the northeast facility boundary that have not been detected simply because there are no wells present to intercept potentially contaminated zones. The lower concentrations of PCE and its degradation products seen to the south of monitoring well LMW-4 are indicative of the presence of other DNAPL source locations within the aquifer. The fact that the District has not been able to install wells on the private property on the northern boundary of the facility also skews the appearance of the plume.

The map showing the concentrations of dichloroethane (Figure 7) perhaps demonstrate the nature of the plume better than the other three. As noted above, dichloroethane is a degradation product of both PCE and 1,1,1-TCA. It is somewhat less dense and viscous than the parent chemicals, and therefore disperses a little more evenly through the aquifer. It is clear from that graphic that the plume is moving in concert with the groundwater flow.

Again, because DNAPLs are dense, and sink in water, they will not disperse evenly throughout the aquifer. Pools and pockets of the PCE/TCA contaminants will develop at different elevations and in differing concentrations. Down-gradient sampling locations may or may not be placed in exactly the precise positions to detect all of the contamination. This becomes a serious obstacle to the delineation of DNAPL plumes in general, and appears to be a major factor in skewing the appearance of the plume at the Logan landfill.

### **Contaminant Source**

As noted previously, soil samples from the newly-drilled test borings were analyzed for the presence of VOCs, and none of the samples showed any signs of contamination. Monitoring well LMW-6 was drilled less than ten feet from the edge of the existing unlined waste cell, where the potential for contamination was initially considered the highest. Yet none of the samples from that test boring yielded any evidence of contamination, including a sample taken from the capillary fringe of the water table where some of the lighter contaminants would certainly be detectable had there been seepage from the historic waste area.

The original investigators who conducted the initial CMA considered that the DNAPLs were emanating from somewhere within the waste fill area as a consistent, slow dribble into the aquifer. However, given the nature of DNAPL behavior in groundwater and the geological conditions on the site, we have concluded that this is not the case.

In the first place, we were unable to delineate strata that would act in any way as a single, impermeable surface above the aquifer that would allow migration of contaminants from the waste area to the northeastern corner of the facility where the contamination has obviously entered the aquifer. The geology consists more or less of haphazard groupings of generally permeable sediments that contain apparently lenticular bodies of relatively fine-grained material. The migration route of fluids moving from the surface to the water table will certainly not always be directly vertical, but the discontinuous nature of the more impermeable sediments makes it highly unlikely that fluids will move on the order of hundreds of feet laterally. Even if the dry-cleaning solution was located in the most northeasterly portion of the known waste deposits, it would still have had to migrate laterally through the subsurface some 150 feet in a northeasterly direction to end up immediately up-gradient of monitoring well LMW-4, where the groundwater has the highest concentrations of DNAPL. The wells installed for this investigation are separated by 150 to 250 feet, and we are unable to correlate geological units across those distances with any confidence.

DNAPLs are denser than water, and once introduced into an aquifer will generally move in only one of two directions: downward and down-gradient. These chemicals do not move laterally great distances through an aquifer, unless there are strong channels of preferred flow. That is, if a gravel body runs through a silty sand, then it is possible that the flow of water and anything carried by that water will move preferentially through the more permeable zone, and that the direction of movement may actually be cross-gradient to overall flow, if only for short distances. Unlike the finer-grained nature of the material above the aquifer, the aquifer underlying the Logan landfill is predominately coarse sand and gravel. The existing data don't indicate that water would have any significant preferential pathways within the saturated zone, which makes it highly unlikely that DNAPLs entered the top of the aquifer and migrated laterally.

In addition to the problem of DNAPLs migrating through the subsurface laterally, there is another problem regarding a potential source location. Dry-cleaning facilities have been under regulatory constraints for a number of years, in some cases since the early 1980s. There has probably been no dumping of DNAPLs at this facility since at least the mid- to late 1980s. There is certainly a possibility that drums of dry-cleaning solution are buried somewhere on the facility, but if so, they must be very close to the northeast corner of the licensed area. Those areas have been excavated for a leachate collection pond and a stormwater runoff pond, with no reports of any possible DNAPL sources. The rest of the area does not appear to have been disturbed. In reality, given the nature of the vadose zone geology, the northwesterly direction of groundwater flow, the very high seepage velocities of the groundwater, the lack of preferential pathways that could facilitate lateral migration within the aquifer, and the absence of any evidence of PCE dumping within the waste that has been removed, any existing source of the contaminant would have to lie on the property to the east of the landfill.



The investigators have reached the conclusion that, in essence, there is no longer a significant source of DNAPL above the water table. The most likely reason for the contamination is land application of used dry-cleaning solution. That is, the solution was considered to be so volatile that people simply dumped the fluid onto the ground, assuming that most of it would evaporate into the atmosphere. We see no other logical explanation at the time of this writing. Additional drilling may well uncover other evidence, but for the purposes of this investigation, we must assume that there is no “smoking gun” to be found. The DNAPL was probably dumped at the edge of the dry streambed east of the property for many years until the practice was stopped, probably some time in the 1980s.

The behavior of the contaminant plume supports this hypothesis. What we see in the aquifer at the Logan landfill fits the descriptions of DNAPL behavior in aquifers where the vadose zone contaminant sources have been removed. That is, one observes long-term, consistent, low-level concentrations of DNAPLs and their degradation products. The DNAPLs are entrenched within the aquifer as pools and streaks throughout the sand, and act as a continuous source for contaminants within the aquifer itself. It appears that the actual source area is essentially depleted after decades of leaching downward to the water table. Some product may remain in the vadose zone, but the lack of a mechanism to mobilize such sources and the long-term consistency of DNAPL concentrations found in the groundwater don't really support the concept that a subsurface source is currently providing a continuous “feed” of contaminants.

## **Remedial Alternatives**

The Amended Rules of Montana provide guidance for the potential control and remediation of groundwater contamination. Basically, in this instance, one can attempt to control the source or one can treat the groundwater. The following discussion addresses the options available to the Gallatin County Solid Waste Management District for the remedial actions at the Logan landfill.

### **No Action**

**Alternative A. No Action.** The No-Action alternative can be used in some cases as a viable option. It is always used as a yardstick to determine the potential value of other options. In this case, the No-Action option would amount to a monitored natural attenuation option. No remedial action would be taken, but the site would continue to be monitored. If the property to the north of the landfill was owned by the Gallatin County Solid Waste Management District, this might actually be a viable option, if appropriate levels of bioremediation could be documented via additional groundwater monitoring wells. However, since this is not currently the case, other options must be considered.

## Source Management

One common approach for effective groundwater remediation involves control of the contaminant source. The source can be removed, if possible, or various applications can be developed to treat the source in place. Air sparging, the construction of vertical cutoff walls combined with pump-and-treat strategies, chemical oxidation of the contaminants, etc. are all options. However, it is not clear that there is actually any significant, treatable source of DNAPLs remaining above the water table. Nonetheless, it may be possible to delineate an area where the dry-cleaning fluid was land applied and develop a treatment. Should an existing source be found, there are several options for treatment.

**Alternative B. Source Removal.** The area of potential contamination would need to be clearly identified via drilling or direct-push technologies. It is entirely conceivable that an area as big as ten to twenty thousand square feet would have to be removed to a depth of 35 to 45 feet or deeper. Given the exploratory costs, the costs of developing a construction technique, the cost of containment, transport and disposal of hazardous waste, and the simple safety factors of excavating an area that large on the facility property, this is not considered a feasible option. The cost of removal for this option is estimated to be three to seven million dollars.

**Alternative C. Source Treatment.** If a source zone can be clearly identified, there are several remedial options, including chemical oxidation and thermal treatment. These have proven effective at sites with PCE contamination.

**Discussion.** Source removal or control in this situation is simply infeasible for a number of reasons. First and foremost, the investigators are convinced that the odds of actually finding a single contributing DNAPL source 20 years after the cessation of dumping is highly unlikely. The cost of finding the location of the source alone would greatly exceed one hundred thousand dollars in drilling and sampling costs. The cost of developing a removal or treatment remediation and then implementing it could well range into the millions of dollars. With all of that work completed, there would still be no treatment of the DNAPL that is currently trapped within the aquifer. Since it is improbable that there is a constant source of DNAPL migrating from the surface or near surface into the aquifer, removal or treatment of a potential source cannot be recommended as a remedial option.

## Groundwater Treatment

The groundwater at a contaminated site can be treated via any number of methods. The known options are discussed below.

**Alternative D. Pump-And-Treat.** The groundwater at the facility can potentially be treated via a method of removal of the water, treatment of the water and re-

injection into the aquifer. Unfortunately, a number of publications indicate that this pump-and-treat methodology is not very effective for low concentrations of PCE. The reason for this is that the DNAPL is pooled within the aquifer and is never truly removed by pumping. The contaminant slowly contributes small portions of chemical constituents that are removed from the groundwater, but those pooled and smeared zones of DNAPL continue to act as sources for decades. Any pump-and-treat operation would, therefore, have to continue for decades. Such an undertaking would entail the installation of a number of wells for water withdrawal, a treatment plant would have to be designed and constructed, and injection wells would have to be installed. Given the very high productivity of the aquifer, such a plant would have to process, conservatively, half a million gallons of water per day. The design, construction and operating/maintenance costs of such a system would be extremely high, into the millions of dollars just to get it on-line. Then, as noted above, the plant would have to be operated probably for decades into the future. Pump-and-treat options are now rarely applied to PCE contamination in aquifer for these reasons.

**Alternative E. *In-Situ* Co-solvent Surfactant Treatment.** Another means by which PCE can be treated in an aquifer is to inject a surfactant into the aquifer. This, in essence, chemically breaks down and mobilizes contaminants. The groundwater is then either left to flow naturally, or it is removed via pumping and further treatment. The problematic nature of pump-and-treat systems is discussed above in Alternative D. In addition, unless the groundwater downgradient of the facility was removed, there is a high probability that the surfactants used to break down the DNAPL would leave residual chemicals that, in and of themselves, would represent an additional human health hazard. Thus, the facility might come into compliance with regard to the dry-cleaning fluid contamination, but might end up being out of compliance with regard to the treatment chemicals.

**Alternative F. Enhanced Bioremediation.** The anaerobic groundwater underlying the Logan landfill is apparently creating an environment that is conducive to the growth of organisms that are actively breaking down the DNAPLs. Evidence of this lies in the fact that there are concentrations of degradation products of the PCE and TCA in the groundwater, in the form of trichloroethene and dichloroethane. Microorganisms living in the aquifer come into contact with these chemicals, and use them as an energy source by breaking the bonds of the chlorine ions. Thus, they naturally de-chlorinate the contaminant molecules to a point where they become ethylene. Further addition of a hydrogen ion through a reaction involving sulfur turns the ethylene into ethanol, or simple alcohol. This is, essentially, a fermentation process that breaks down the DNAPLs the same way a surfactant does, without the introduction of chemicals that can potentially create additional contamination problems. Treatment of the aquifer using enhanced bioremediation requires the introduction of additional nutrients and catalysts to the water in the subsurface. In its simplest form, these treatments consist of pumping simple products such as



molasses and cheese whey into the subsurface. More sophisticated products are available, but they all work on the same principal. The microorganisms require a sugar molecule, in the form of lactose, or milk sugar, and the process is enhanced by the presence of sulfur, which can be found in the molasses. More sophisticated products also add hydrogen to the groundwater as a means of keeping the environment anaerobic, as well as aiding in the degradation of the ethylene. The specific mixture to be injected will have to be examined closely, and the final choice of products will be based on the seepage velocity of the groundwater, the type of microorganisms in the aquifer, etc. The nutrient injections might need to occur every year or two, and it might be necessary to inject an additional culture of the microorganisms, if the populations are currently inadequate.

### **Cost of Treatment**

This site could be treated with range of options, some of which are clearly not feasible. Therefore, we did not conduct an exhaustive examination of the costs for each option. Table 1 is a summary of costs tabulated by the EPA for a range of treatment options related to PCE contamination. Some of the items represent costs accrued at sites that were faced with the removal or treatment of significant quantities of soil that constituted sources of contamination. The Logan landfill is not necessarily facing the prospect of source treatment, but the cost of treatment of contaminated aquifers will be similar or higher than those listed.

**Table 1. Comparison of costs for various PCE treatment options.**

Option	Investigative Requirements	Site-Specific Costs	Typical Costs	Pros	Cons
<b>Source Control/Reduction</b>					
Alternative B. Remove Source (assume 85,000 yards)	Source has to be found, clearly identified, removed to depths of nearly 50 feet in unconsolidated material; will require closely-spaced drilling or direct-push investigation, design of removal/control based on concentrations of DNAPLs delineated.	Drilling; sample analysis; construction feasibility study; construction/excavation costs; contaminant containment, shipping and treatment; replacement of soil.	Unknown; assuming \$10/yd removal and \$75/yd transport and treatment, cost could exceed \$7 million.	Source would be permanently removed.	DNAPL in aquifer is not affected and would still require treatment; feasibility of removing soil in an area 150 x 100 feet to a depth of 40 to 50 feet is questionable.
Alternative C. Thermal or Chemical Oxidation	Same as source removal, above.	Investigative costs, design costs, construction costs, O&M.	\$90 to \$125 per cubic yard of aquifer median; range \$32 to \$518 per yard.	Source might be permanently controlled.	Air sparging and other methods are not particularly effective on DNAPLs; DNAPLs in aquifer would still require treatment.
<b>In-Situ Aquifer Treatment</b>					
Alternative D. Pump-and-Treat	Intensive studies on groundwater/aquifer interaction and flow; intensive studies to determine concentrations of contaminants throughout the aquifer; studies to determine possible recoverable quantities.	Three to five additional wells on east boundary; two to four additional wells to determine specific aquifer characteristics; design & construction of pumping, treatment and re-injection system.	Not typically used for PCE contamination in aquifers.		Generally ineffective for DNAPLs; extremely expensive; very long-term operations required.
Alternative E. Cosolvent Surfactant	One to three additional wells on east boundary, two to four wells to determine specific aquifer characteristics, additional sampling for design of chemical treatment, design of injection system and, if required, removal system.	Drilling, sample analysis, construction feasibility, design, implementation, O&M.	\$385 to \$1,300 per cubic yard of aquifer median; range \$66 to \$5,500 per yard of aquifer.	Removes potential long-term sources of contaminants in aquifer.	Very expensive, requires similar efforts as pump-and-treat if surfactant has to be removed, may leave surfactant residuals in groundwater that represent health hazards
Alternative F. Enhanced Bioremediation	Additional wells to determine optimal injection points, biological sampling for effective microorganisms, design of injection system, varying nutrient concentrations over time for maximum impact.	Drilling, sample analysis, purchase of nutrients/biological enhancement products.	\$27 to \$29 per cubic yard of aquifer median; range \$2 to \$225 per yard.	Relatively inexpensive, highly effective, low impact to aquifer, no additional treatment outside of aquifer confines, readily customized and manipulated.	Long-term commitment, adjustment of nutrient loading sometimes required, sometimes difficult to administer nutrients in some aquifers

## Preferred Alternative

As noted above, the DNAPL contamination within the aquifer underlying the Logan landfill is representative of a site in which the contaminant source is essentially depleted and the observed contamination is emanating from DNAPLs and their degradation products that are entrenched within the aquifer itself. Additional contamination may be entering the aquifer from the vadose zone, but such a source may not be easily identifiable. It seems most likely that the dry-cleaning solution was land-applied, and the application of the contaminants ceased more than 20 years ago, leaving only relatively small residual components in the vadose zone.

Great West Engineering recommends that Option F be approved by the DEQ. Option F involves enhanced bioremediation of the aquifer. All of the other options require very expensive, marginally feasible and/or marginally effective techniques. Bioremediation is already occurring at this facility, and the process has been adopted more and more frequently in recent years as the “feeding” of the microorganisms has become better understood by scientists.

Bioremediation may require some further characterization of the aquifer, most likely in the form of one or two additional monitoring wells on the northeast boundary. The additional data at that point should be obtained by installing a well the full length of the aquifer, and perhaps nesting a number of monitoring wells in a large-diameter hole. This will allow for more precise testing of the aquifer characteristics, such as grain size and hydraulic conductivity. In addition, these borings might also help delineate the likely source of the original contamination, even though that source may not currently be present or active. Again, this may not be required to treat the existing plume, and, given the nature of DNAPL transport in groundwater, one would want to be careful that such installations don't result in the additional mobilization of contaminants.

An appropriate remedial product must be identified and tested at the site. Perhaps the most prudent approach would be to develop a pilot testing program that would involve treating the most highly impacted zone. The pilot program would probably consist of installing three to five injection wells through the full thickness of the uppermost aquifer. The selected product would be injected and the down-gradient wells would be monitored for VOCs for a period of 6 to 12 months. The need for additional injection wells and/or product applications would be evaluated after that time. The pilot testing program would require approximately \$15,000 to \$20,000 in drilling costs and approximately \$50,000 to \$75,000 in product costs.

## Conclusion

Monitoring wells at the Logan landfill have been producing groundwater samples containing low levels of volatile organic chemicals since the initiation of sampling in 1990. Concentrations of dense non-aqueous phase liquids in the form of dry-cleaning solution rose in the late 1990s to a point where the human health standard for tetrachloroethene were exceeded in one well. Removal of existing solid waste in an unlined area of the facility did not result in any measurable change in the groundwater contamination levels. This document represents the second effort to address the groundwater contamination at the Logan landfill.

The original source of the DNAPLs was probably within the vadose zone where land-applied dry-cleaning fluid permeated the relatively sandy soils. Dumping of the solution probably ceased during the 1980s, and the remaining contaminants either volatilized or migrated to the water table, which is less than thirty feet below ground surface in the area of suspected dumping. Some of the DNAPL may remain in the vadose zone, but the consistency of the groundwater contamination indicates that the source has probably been largely depleted. The site shows similarity to other sites in which the source of the contamination has been removed.

DNAPLs tend to sink in aquifers and end up pooled within a relatively large three-dimensional area from top to bottom. Pools and streaks of the contaminants remain in the aquifer and continue to bleed into the aquifer for many decades. Treatment of such low-level sources has been shown to be problematic. However, the presence of degradation products in groundwater samples indicates that bioremediation is occurring at least to some degree at the Logan site. Given that the process is already at work, the logical choice for remediation is an in-situ treatment using bioremediation enhancements. Other options, such as source treatment of the vadose zone, are simply not feasible or prohibitively expensive.

The investigators have recommended, therefore, that Option F, in-situ bioremediation, be implemented for the Logan landfill PCE/TCA contamination. The treatment should be undertaken in a step-wise fashion, starting with an initial pilot program to determine that the chosen treatment product will be effective. The specific treatment option can be expanded or otherwise manipulated based upon the results of the pilot program.



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## **Appendix A**

### **Logs of test borings at the Logan landfill, Gallatin County, Montana**

## **Appendix B**

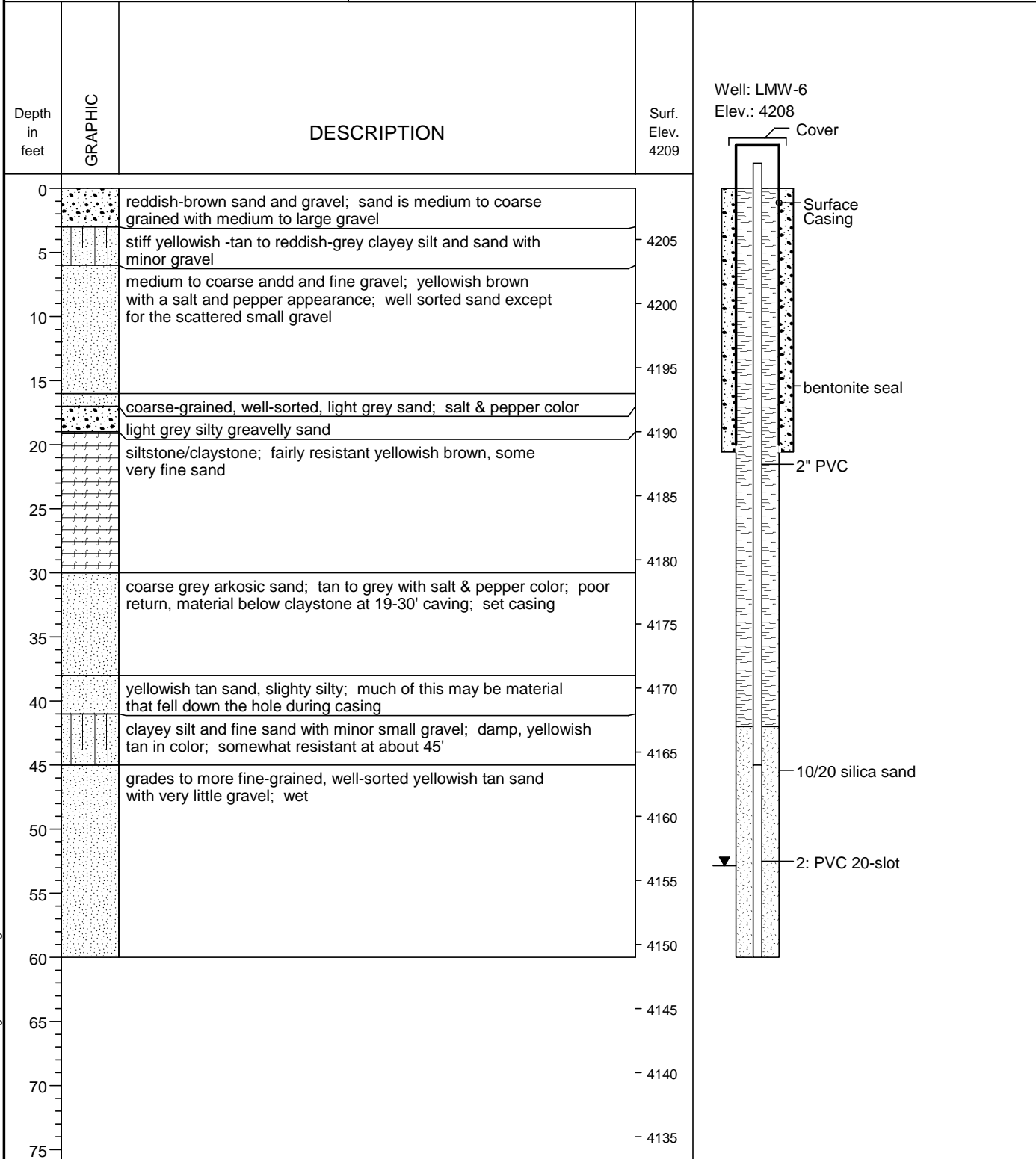
### **Laboratory Analysis Reports Logan Landfill, Gallatin County, Montana**



# LOG OF BORING LMW-8

(Page 1 of 1)

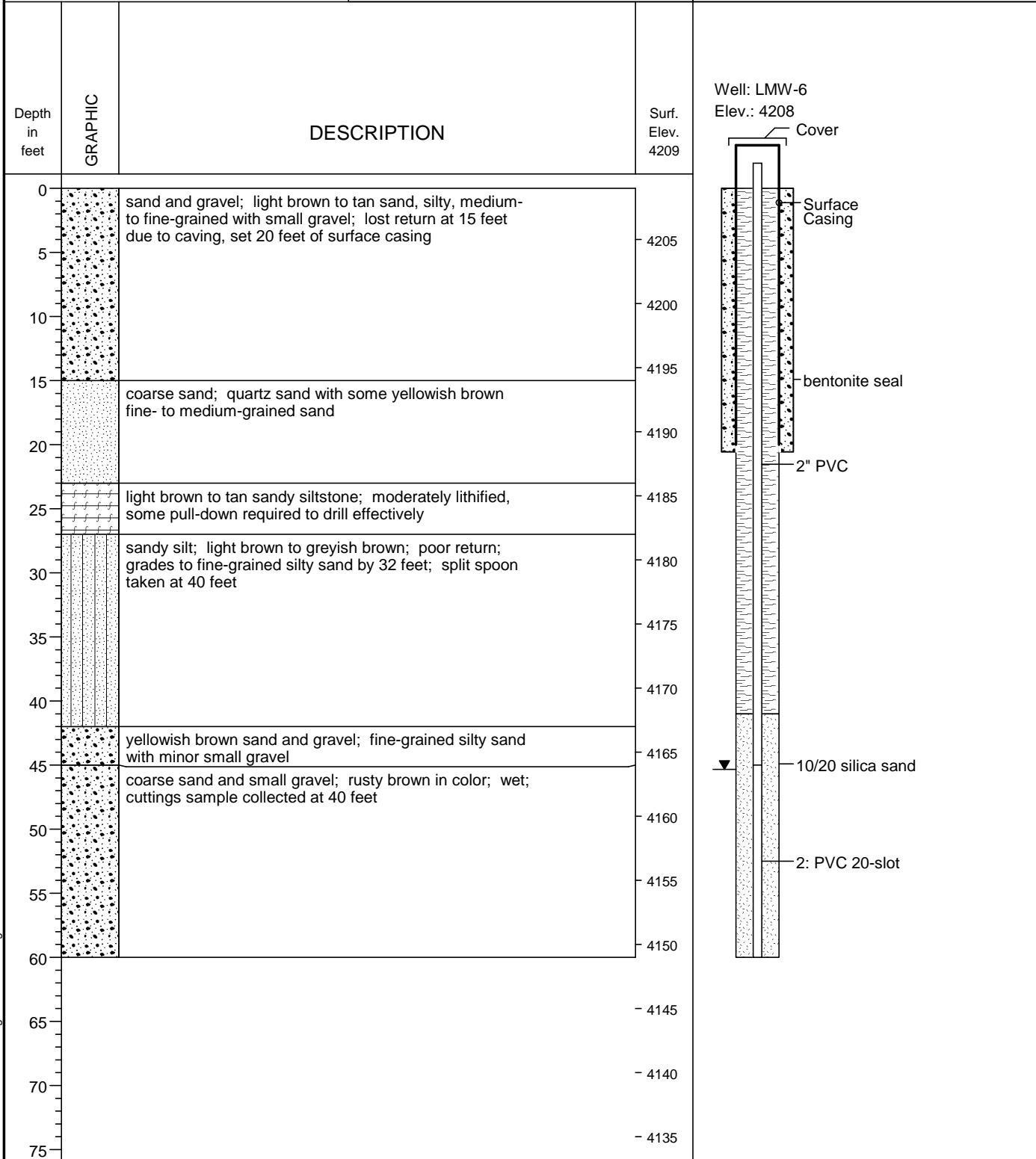
Project Number : 1-05119  
Date : 5/24/06  
Drilling Firm : O'Keefe Drilling  
Drilling Method : air rotary  
Geologist : B. Siegmund



# LOG OF BORING LMW-7

(Page 1 of 1)

Project Number :  
 Date : 5/23/06  
 Drilling Firm : O'Keefe Drilling  
 Drilling Method : air rotary  
 Geologist : B. Siegmund



# LOG OF BORING LMW-6

(Page 1 of 1)

Project Number :  
Date : 5/22/06  
Drilling Firm : O'Keefe Drilling  
Drilling Method : air rotary  
Geologist : B. Siegmund



Depth  
in  
feet

GRAPHIC

DESCRIPTION

Surf.  
Elev.  
4201.44

Well: LMW-6

Elev.: 4202.76

Cover

Surface  
Casing

bentonite seal

2" PVC

10/20 silica sand

2: PVC 20-slot

08-15-2006 c:\BL\SL\logan\CMA\well logs\LMW-6.BOR

0	tan to brown silty sand, fine-grained, some scattered pea-sized gravel	4200
5		4195
10	light brown sand, medium- to fine-grained, salt & pepper appearance; grades to greenish-grey fine sand	4190
15		4185
20	sandstone; tan to greyish brown; fine-grained, silty; split spoon collected	4180
25	very fine-grained silty sand; poorly sorted with some scattered coarser sand; light brown to tan	4175
30		4170
35	fine-grained silty sand, as above, but increasing fraction of medium to coarse grains with depth; poor return	4165
40	silty sand, but more resistant; slightly wet; no return; dark grey-green and relatively hard; sampled w/ split spoon but material is very resistant and little sample was returned.	4160
45	fine- to medium-grained sand, slightly silty, salt & pepper appearance; generally brownish-grey when dry	4155
	brown silty sand with minor gravel; wet	
50	grading to reddish-brown silt with gravel and minor sand	4150
55		4145
60	medium-grained sand with gravel; sand is brown with salt & pepper appearance; gravel is predominately medium-grained, much of it composed of black chert	
65		4140
70		4135
75		4130

# LOG OF BORING LMW-5

(Page 1 of 1)

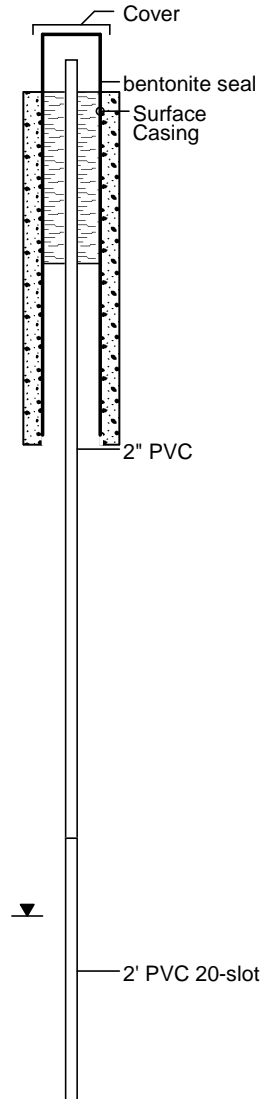
Project Number : 1-05119  
 Date : 12/20/94  
 Drilling Firm :  
 Drilling Method : air rotary  
 Geologist : K. Gallagher



Depth in feet	GRAPHIC	DESCRIPTION	Surf. Elev. 4201.6
0		silt loam	4200
5		coarse brown sand	4195
10		sand and gravel	4190
15		silty sand, yellow-brown with some fine gravel	4185
20			4180
25		silty sand	4175
30		silty sand	4170
35			4165
40		coarse brown sand	4160
45		silty brown sand	4155
50		sandstone, dark gray, hard	4150
55		sand and gravel, grading to silty sand	4145
60		silty sand, yellowish-brown	4140
65			4135
70			4130
75			

Well: LMW-5

Elev.: 4201.6





# LOG OF BORING LMW-4

(Page 1 of 2)

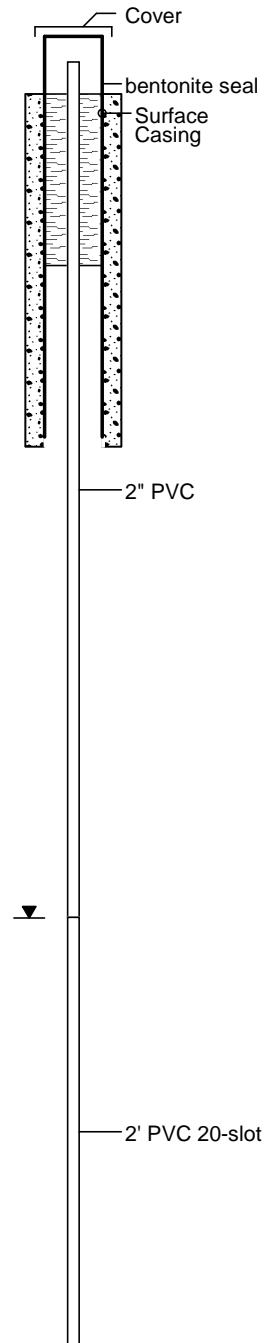
Project Number : 1-05119  
Date : 12/20/94  
Drilling Firm :  
Drilling Method : air rotary  
Geologist : K. Gallagher



Depth in feet	GRAPHIC	DESCRIPTION	Surf. Elev. 4208.6
0		silt loam	
5		silty fine sand, brown, poorly graded, <10% medium to coarse gravel, sub-rounded, calcareous	4205
10		sand and gravel; well-graded predominately medium to coarse sand with fine to coarse, well-rounded gravel, coarsening to 12' and fining predominately moderately well-graded sand at 16', fines to poorly-graded coarse sand; Slightly calcareous in upper portion	4200
15			4195
20			4190
25		silty clayey sand; yellowish brown, medium to coarse, moderately well-graded	4185
30		silty very fine sand, yellowish brown, poorly graded	
35		sand, very fine to fine, tuffaceous, slightly silty, becoming siltier with depth	4180
40			4175
45			4170
50		sand and sandstone, dark gray, very fine, slightly silty	4160
55		as above, but siltier, softer and unconsolidated	4155
60		sandstone, dark gray, hard	4150
65			4145
70			4140
75			4135

Well: LMW-4

Elev.: 4208



# LOG OF BORING LMW-2

(Page 1 of 1)

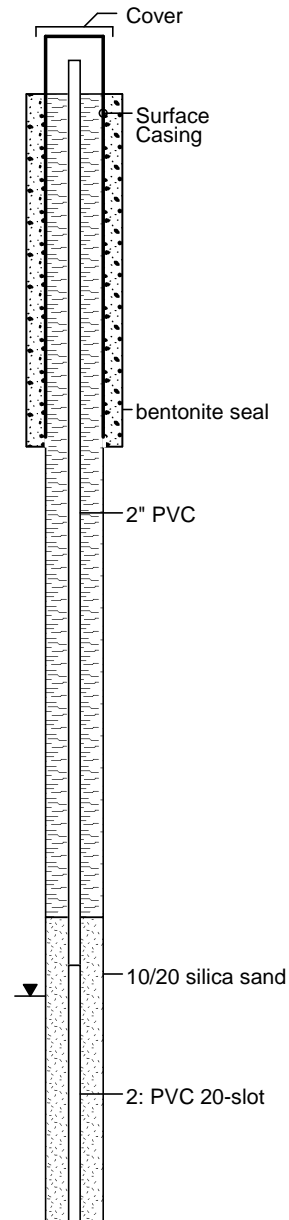
Project Number : 1-05119  
Date : 8/27/90  
Drilling Firm :  
Drilling Method : air rotary  
Geologist : Schafer



Depth in feet	GRAPHIC	DESCRIPTION	Surf. Elev. 4216.5
0		silt loam, dark to light brown, calcareous, dry	4215
5			4210
10		silty sand, light brown, fine to medium, moderately graded; gravel increasing with depth; calcareous	4205
15		sandstone; silty, very fine-grained, light brown, soft	4200
20			4195
25		sand and gravel; yellow brown; medium to coarse sand and fine to coarse gravel; well graded; subround to round, coarsening to coarse gravel from 32.5 to 33.5	4190
30		sand & gravel	4185
35		sandy silt, yellowish brown	4180
40		claystone; yellow-brown, interbedded sandstone	4175
45		sandy clay, buff	4170
50		sand; grey brown	4165
55		silty sand; yellow brown	4160
60		siltstone/claystone	4155
65			4150
70		sandstone, gray, gravel at depth	4145
75		sandstone, dark gray br, wet	
		sand, grey brown, 10% small gravel at depth	

Well: LMW-2

Elev.: 4217.12



# LOG OF BORING LMW-1

(Page 2 of 2)

Project Number : 1-05119  
 Date :  
 Drilling Firm :  
 Drilling Method : air rotary  
 Geologist : Schafer



Depth  
in  
feet

GRAPHIC















DESCRIPTION

Surf.  
Elev.  
4221

Well: LMW-1  
 Elev.: 4221

2' PVC 20-slot

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75		sandstone & claystone	4145
		sand, silty, fn	
80		sand and gravel, somewhat cemented	4140
		sandstone, fine w/ interbedded claystone	
85			4135
90		sandstone and claystone	4130
95			4125
100		sandstone, clayey, siliceous, hard	4120
105		sandstone, brown, siliceous	4115
110			4110
115			4105
120		sandstone, v fn gr	4100
125			4095
130		gravel and sand	4090
135			4085
140			4080
145			4075
150			

# LOG OF BORING LMW-1

(Page 1 of 2)

Project Number : 1-05119  
Date :  
Drilling Firm :  
Drilling Method : air rotary  
Geologist : Schafer



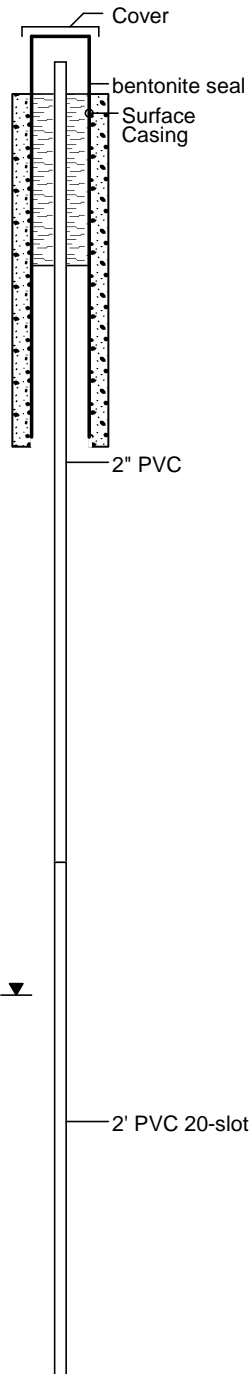
Depth  
in  
feet

GRAPHIC

DESCRIPTION

Surf.  
Elev.  
4221

Well: LMW-1  
Elev.: 4221



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0	silt loam	4220
5	silty sand, med-crs	4215
10	sand & gravel	4210
15		4205
20	sand, v. fine, weakly consolidated	4200
25		4195
30	sand and gravel sand, crs to fine	4190
35	sand and gravel	4185
40	sand, fn to crs, coarsening w/ depth	4180
45		4175
50	sand and gravel, some sst stringers sand, fn to crs, some gravel	4170
55		4165
60	sand and gravel	4160
65	sand, fn to med	4155
70		4150
75		

# LOG OF BORING LMW-9

(Page 1 of 1)

Project Number : 1-05119  
Date : 5/24/06  
Drilling Firm : O'Keefe Drilling  
Drilling Method : air rotary  
Geologist : B. Siegmund

